Changes in Soil Organic Carbon of Crop Rotations in the Northern Corn Belt

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Abstract

Diversified crop rotation may reduce fertilizer nitrogen (N) input for corn (Zea mays L.) and increase soil organic carbon (SOC) storage. Objectives were to determine effect of rotation and N on soil C sequestration. The experiment, started in 1990, was on a Barnes sandy clay loam near Brookings, SD. Since 1996, primary tillage was chisel plow on all rotations. Prior to 1996, moldboard plow was used. All crop residues were returned to the soil. Crop rotations were: continuous corn (CC), corn-soybean [Glycine max (L.) Merr.] (CS), and a four-year rotation of corn-soybean-wheat (Triticum aestivum L.) companion seeded with alfalfa (Medicago sativa L.)-alfalfa hay (CSWA). Non-cropped treatments included warm season, cool season, and a mix of warm- and cool- season perennial grasses. Nitrogen treatments for corn were: corn fertilized for a grain yield of 8.5 Mg/ha (N1), 5.3 Mg/ha (N2), and no N (noN). During a four-year-rotation cycle, 35 percent less tillage was used on CSWA compared to CC. Corn yield under CSWA with noN was 91% of the yield attained under CC with N1. Soil organic C (0 to 15 cm) under grass increased 3.75 Mg C/ha from 1996 to 2006. Continuous corn under N1 returned about 1.6 times as much above-ground-plant C (PC) to the soil as CSWA. Under N1, there was a loss of -2.3 Mg C/ha (0 to 15 cm) from CC and a gain of 0.3 Mg C/ha from CSWA (1996 to 2006). A combination of greater crop diversity and less tillage on CSWA, compared with CC, likely contributed to a balance of SOC (return of crop C ≈ loss of SOC). In contrast, corn stover returned at a rate of 7.02 Mg/ha/year (average 1990 to 2005) under CC with N1 was not enough to offset SOC loss.

Introduction

Effects of crop and soil management practices on soil condition are often clouded by variability within a system. Further, causal relationships between management and soil quality are difficult to extrapolate among regions because of differences in soil type, climate, and management norms. Generally, it is accepted that conversion to crop production practices has caused a decline in soil organic carbon (SOC) compared to the original grassland levels throughout the Great Plains. Tillage has caused losses (from 28 to 77%) in SOC depending on geographic location and soil type. Changes in agricultural management from conventional tillage to no tillage and increased crop-rotation diversity can increase accumulation of SOC.

There is potential for using innovative soil and crop management to sequester atmospheric carbon. Crop rotation, residue management, fertility management, and tillage management have a direct impact on carbon cycling and sustainability of the soil resource. But, there are unresolved questions concerning the quantity of carbon that can actually be sequestered in soil and the time frame involved in that sequestration. Corn produces a large amount of crop residue and this residue is currently being viewed as a source of cellulosic feedstock for ethanol production. There are risks associated with wholesale removal of crop residues, and the long-term consequences of residue removal are poorly understood. These risks include exacerbating soil erosion by water and wind, depletion of soil organic matter, degradation of soil quality, and reduction of agronomic productivity.

This research investigates effect of crop rotation and fertilizer N on soil C sequestration and indirectly addresses questions of how much crop residue must be retained on the soil to sustain soil productivity.

Materials and Methods

♦Location: Experiment started in 1990 at Brookings, South Dakota (Fig. 1).
♦Soil: Barnes sandy clay loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll).
♦Crop rotations: RCB, split plot, 3 replications. All crops each year.
- Corn (CC)
- Corn-soybean (CS)
- Corn-soybean-wheat/alfalfa-alfalfa. Alfalfa and wheat are companion (Fig. 1a) seeded in year 3 of this 4-year rotation (CSWA).
- Perennial grass (warm season, cool season, and mixtures)

♦Tillage
- Fall chisel plow, seedbed preparation with tandem disk and field cultivator. Corn and soybean row-cultivated once.

♦N prescription (NP) for specific yield goals (YG) of corn grain.
NP = 0.022YG - STN (Soil test nitrate-N). Starter fertilizer with seed at 112 kg/ha 14-36-13, 7-36-13, and 0-36-13 on N1, N2, and noN, respectively. Urea (46-0-0) side dressed to meet NP before row cultivation.
- ✓N1: Corn fertilized with N for a YG of 8.5 Mg ha^{-1}
- ✓N2: Corn fertilized with N for a YG of 5.3 Mg ha^{-1}
- ✓noN: no N fertilizer

♦Fertilizer for other grains
- Soybean: starter fertilizer at 112 kg/ha 14-36-13, 7-36-13, and 0-36-13 on N1, N2, and noN, respectively.
- Wheat: starter fertilizer 112 kg/ha 14-36-13, 7-36-13, and 0-36-13 on N1, N2, and noN, respectively. NP = 0.046YG - STN. Urea (46-0-0) broadcast to meet NP prior to field cultivation.
  - ✓N1: wheat fertilized with N for a YG of 4 Mg ha^{-1}
  - ✓N2: wheat fertilized with N for a YG of 3 Mg ha^{-1}
  - ✓noN: no N fertilizer

♦Grain yield measured by harvesting 8 rows, 31 m long (Fig. 1b). C and N measured using dry combustion.
♦Soil measurements
- Initial soil condition: 315 spatial samples on a 30 x 30-m grid August 1989. Cores (5 cm dia.) taken from the top 20 cm. Sample locations within crop experiment shown in Fig. 1 (lower).
- All-plot sampling: 1996, 2000, and 2006
- Selected-plot sampling: 1998, 1999, 2001, and 2002
- Samples: 6 cores (3.2 cm dia.) from 0- to 7.6-cm and 7.6- to 15-cm (or 0-15 cm). Dry combustion method for determination of total C and N in soil from 1989 to 2006.

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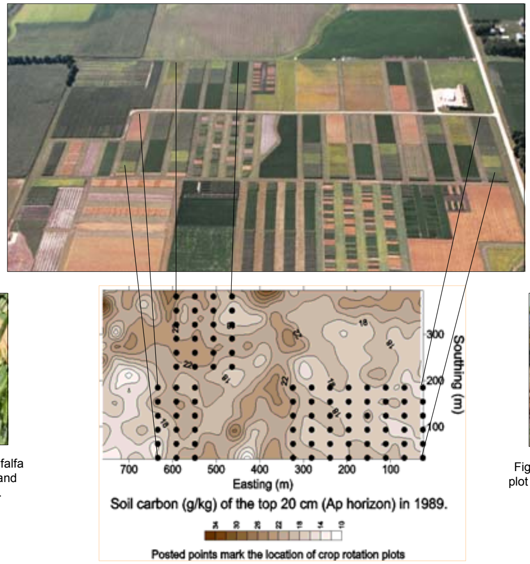

Figure 1a. In year 3 of the CSWA rotation, alfalfa was companion seeded with spring wheat and subsequently harvested for hay in year 4.

Figure 1b. Corn grain yield measured using a plot combine and harvesting 8 rows, 31 m long.

Figure 1. Aerial photograph (upper) showing crop rotation plots. Each main block is 30 x 90 m. Sub-plots (N treatments) are 30 x 30-m. Crop color within blocks generally reflects N treatment. Contour map (lower), is an overlay of the distribution of soil C in 1989. Each black dot corresponds to the center location of each sub-plot in the crop rotation study.

Table 1. Total above-ground-plant C and N returned to the soil during 1990-2005 for rotations of continuous corn (CC), corn-soybean (CS), and corn-soybean-wheat/alfalfa-alfalfa (CSWA). Nitrogen fertilizer treatments for corn were corn fertilized for a yield of 8.5 Mg/ha (N1), corn fertilized for a yield of 5.3 Mg/ha (N2), and corn not fertilized (noN).

	Fertilizer N			
Rotation	N1	N2	noN	Average
		------ Plant C (kg/ha) ------		
CC	48980	41300	27940	39410 C
CS	34810	32550	25680	31020 B
CSWA	30050	27580	24630	27420 A
Average	37950 c	33810 b	26080 a	
		ANOVA		
Rotation (R)		***		
Fertilizer (F)		***		
R x F		***		
		------ Plant N (kg/ha) ------		
CC	661	450	237	449 C
CS	997	881	738	872 B
CSWA	1015	948	814	925 A
Average	891 c	759 b	596 a	
		ANOVA		
Rotation (R)		***		
Fertilizer (F)		***		
R x F		***		

Means followed by different upper case letters (comparison of rotations) and lower case letters (comparison of N treatments) are significantly different at the 0.001 probability level (***).

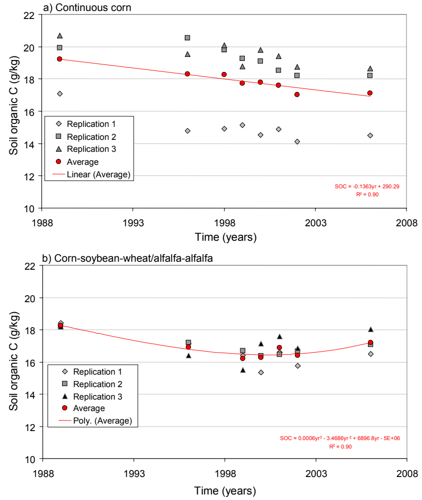

Figure 2. Soil organic C (0 to 15 cm) on each plot (replication) from 1989 to 2006 for rotations of continuous corn (1a) under N1 fertilizer and corn-soybean-wheat/alfalfa-alfalfa (1b) under noN fertilizer.

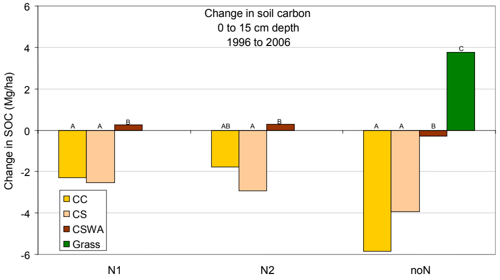

Figure 3. Change in soil organic C (SOC) from 1996 to 2006 under crop rotations and perennial grass. Means within each N treatment (N1, N2, and noN) followed by the same letter were not significantly different (0.05 probability level).

Results

✓ Corn yield on CS exceeded both CC and CSWA under N1. Under noN, corn yield was significantly greater under CSWA compared with CC and CS (Pikul et al., 2005).

✓ Continuous corn under N1 returned about 1.6 times as much PC to the soil as CSWA, but lost -2.3 Mg SOC/ha from the top 15 cm of soil from 1996 to 2006 (Table 1, Fig. 2 and 3).

✓ Under N1, CSWA returned the least PC to the soil compared with CC and CS, but gained 0.3 Mg SOC/ha from 1996 to 2006 (Table 1 and Fig. 3).

✓ On average (all N treatments), CSWA returned the least PC to the soil compared with CC and CS, but crop residues from CSWA returned the greatest amount of N to the soil compared with CC and CS (Table 1).

✓ Concentrations of SOC (time-trend from 1990 to 2006) under CC appear to be in a continued state of decline in contrast to CSWA where an equilibrium condition was possibly reached in 2000 (Figs. 2a and 2b).

✓ Soil C in the top 15 cm significantly increased (3.75 Mg SOC/ha) from 1996 to 2006 with perennial grass cover (Fig. 3).

Conclusions

Corn captures significant amounts of C. However, only a small fraction of plant C may be retained in the soil. Continuous corn under N1 returned about 1.6 times as much PC to the soil as the CSWA rotation. Yet, under N1, SOC loss with CC was nearly ten-fold greater than CSWA. Soil productivity is related to both quantity of SOC and quality of soil organic matter as well as other factors. The historic good yield of corn on the CSWA rotation may reflect soil-improvement on this rotation.

Our findings on C storage are relevant to the top ten corn production counties in eastern South Dakota as an estimate to reasonable rates of SOC accumulation or loss. In respect to corn production, average (1990-2005) non-irrigated corn grain yield was 7.2 Mg/ha (115 bu/acre) for the top producing counties in SD. Average corn yield (1990-2005) for CC under N1 was 6.8 Mg/ha (108 bu/acre). Therefore, the quantity of corn residue returned to the soil of our plots under CC would be typical for eastern SD.

Continuous corn produces a large amount of crop residue and this residue is currently being viewed as a source of cellulosic feedstock for ethanol production. There are risks associated with wholesale removal of crop residues, and the long-term consequences of residue removal are poorly understood. These risks include exacerbating soil erosion by water and wind, depletion of soil organic matter, degradation of soil quality, and reduction of agronomic productivity.

In our studies, all crop residues in all rotations were returned to the soil and we show that the potential to sequester C was very limited under rotated corn (CSWA) and not possible under continuous corn at a production level of 6.8 Mg/ha per year.

References

Pikul, J.L. Jr., L. Hammack, and W. E. Riedell. 2005. Corn Yield, Nitrogen Use and Corn Rootworm Infestation of Rotations in the Northern Corn Belt. Agron. J. 97(3):854-863.

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